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Explosion characteristics of H_2/CH_4/air and CH_4/coal dust/air mixtures

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ABSTRACT

Using a standard 20L explosion spherical vessel, the explosion characteristics of H_2/CH_4/air and CH_4/coal dust/air mixtures as well as the solid explosion products were investigated. Results show that the presence of molecular hydrogen yield from coal spontaneous heated process would significantly increase the maximum explosion pressure and pressure rise rate of H_2/CH_4/air mixtures. With the increasing of hydrogen contents in the mixtures, the lower explosion limits decrease correspondingly. In the cases with appropriate hydrogen and methane ratio, the lower explosion limits of the mixture are even smaller than that of each gas components'. The rules of CH_4/air/coal dust hybrid mixtures explosion parameters present a increasing and then decreasing trend with the methane contents in the hybrid mixtures, and the peak values appear at the point that the methane volume fractions is 0.1. Furthermore, dust explosion processes and some influencing factors, such as dust concentration and initial pressure and so on, are also analyzed and discussed systematically. Supported with the scanning electron microscope (SEM) and image processing technology, the surface fractal characteristics of solid explosion products are analyzed and compared for each coal dusts. Research results may have great significance for the hybrid mixtures explosion kinetic reveal, risk assessment and preventions in the coal mine.

1. Introduction

Gas and coal-dust explosions in coal mines are one of the serious hazards for the coal production industry, which has long attracted extensive interests for many researchers and government managers. The explosion concentration limits and explosion overpressures are very important to the understandings and prevention of the gas and coal-dust explosion damages [1,2].

Since full-scale mine explosion tests are very expensive and time-consuming, full-scale coal-dust explosion experiments had only been performed in US to obtain the characteristics of the dust explosion in the coal mines [3]. And now, many scholars turned to study the gas and coal dust explosion characteristics using laboratory-scale tubes. Coal dust explosions have been conducted in laboratory chambers, which mostly include 20L explosion spheres and 1 m^3 explosion chambers. Using the 20L explosion spheres, Cashdollar [4] studied the explosibility of coal dust. The effects of the coal volatility and the particle size were evaluated and the minimum explosive dust concentrations (MEC) and limiting oxygen concentrations (LOC) of different dusts were also measured and compared in 20L and 1 m^3 explosion chambers by Cashdollar [5] and Going [6]. Using two experimental tubes with different diameter and length, Coal dust/air explosion experiments were performed by Bartknecht [7,8]. The dust cloud was generated along the whole experimental tube by injecting dust from a number of equally spaced external pressurized reservoirs. The coal dust/air mixture was ignited by a pocket exploding methane/air mixture. Results show that the maximum flame speeds of the explosion were 500 m/s, and 700 m/s in the long tube with 2.5 m diameter and 130 m at the dust concentration of 250 g/m^3 and 500 g/m^3 respectively. Wolanski, Kauffman and coworkers [9,10] performed dust explosion research using a vertical experimental tube. The dust cloud was formed by charging dust samples at the top of the vertical experimental tube at a mass rate giving the desired dust concentration. The dust cloud was ignited by a hydrogen/oxygen explosion. Grain dust/air explosions and coal dust/air explosions were conducted by Pineau and Ronchail [11,12] in a duct which connected to a vessel. In their experiments, dust was layered initially at the bottom of the duct and it was dispersed and ignited by the powerful explosion. In the experiments by Gardner [13] the dust/air mixtures were formed by blowing air and coal dust through the experimental tube which connected to an ignition chamber. The dust explosion was initiated by a flame jet or chemical igniter.

Liu [14] studied flame propagation in CH_4/coal dust/air mixtures in an 80 mm×80 mm×500 mm chamber. It was found that the presence of methane gas made the coal dust explosion flame propagate faster than a coal dust flame. Moreover, the burning coal particles were seen to move in the same direction as the flame propagated. He found that the maximum overpressure of the coal dust explosion in the tube under the weak ignition conditions was about 70 KPa and the propagation velocity of the pressure wave along the tube was approximately 370 m/s. The minimum concentration for obtaining a coal dust explosion that propagated

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in the tube was 120 g/m^3 [15]. In other experiments, Methane/coal dust/air explosions and suppression characteristic had been studied [16]. The CH_4/coal dust/air mixture was ignited by a 7 m long epoxy propane mist cloud explosion. A deflagration-to-detonation transition (DDT) was observed, and a self-sustained transverse detonation wave was detected in the methane/coal dust/air mixtures. Using explosion suppression agents, such as ABC powder, SiO_2 powder, and rock dust powder ($CaCO_3$), the explosions can be efficiently suppressed by the rapid decrease in overpressure and propagating velocity of the explosion waves.

Using a high speed camera, Bai [17] studied the explosion overpressure and flame propagation speed of the methane/air mixture and the methane/coal dust/air mixture in a large-scale system of 10 m^3 vessels. It was found that the maximum overpressure of the methane/air mixture appeared at 0.75 m away from the ignition point and the thickness of the flame was about 10 mm and the propagation speed of the flame fluctuated around 2.5 m/s with the methane concentration of 9.5%.

Coal is a complex substance. During the heating process, a variety of combustible gases would be released. Using an experimental device, Zhou [18] investigated hydrogen production rules in the simulated fire coal mine. He found that high concentration hydrogen (H_2) would always be produced associated with methane (CH_4) in the unsealed zone. It can be inferred that the presence of released hydrogen gas may have significant influence on the combustion and explosion of coal mine methane.

In present research, using 20 L explosion sphere vessel, the explosion characteristics of H_2/CH_4/air and CH_4/coal dust/air mixtures were investigated systemically and the effects of combustible gases presence on explosion were considered and discussed. During the explosion tests, the mixtures were ignited by a chemical igniter set in the center of the vessel at room temperature and normal pressure. The research results may have great significance for deeply understanding, forecasting and suppressing of coal mine gas and coal dust explosions hazards.

2. Experimental procedure

2.1. Apparatus and methods

In the present research paper, experiments were performed in a standard 20 L stainless steel spherical vessel (Fig. 1) according to the

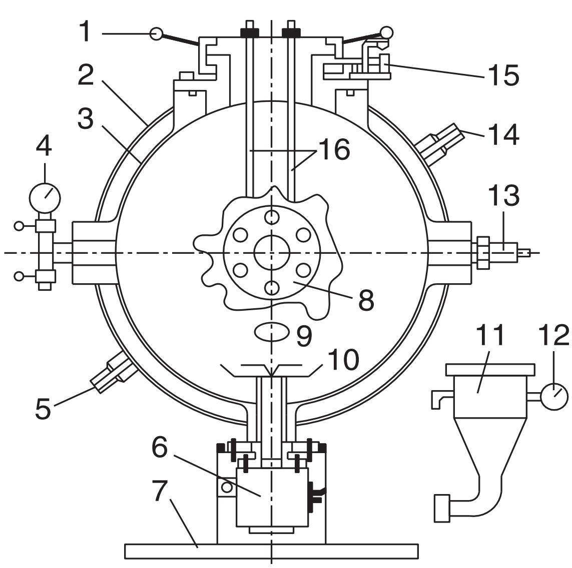

Fig. 1. The 20 L explosion sphere vessel.

international standard ISO6184-1. Before dust explosion test, a pre-weighted amount of coal dust was first placed in dust container (volume: 0.6 L), the centrally mounted chemical igniter was connected with the ignition leads, and the explosion chamber was closed safely. The explosion chamber was partially vacuumed to 0.06 MPa (Absolute) firstly and the dispersing air pressure was set to 2 MPa (Gauge). When the solenoid valve (Made by Kuhner AG Company, Switzerland) between the dust storage container and the test chamber was opened automatically, the air and coal dust were dispersed into the explosion chamber and the chemical igniter was energized after a 60 ms time delay. After the test was finished, the explosion chamber and dust container were thoroughly cleaned with compressed air for the next test [19]. During the mixture explosion experiments, gas concentrations were regulated by the gas partial pressures.

During the experiments, the explosion pressure evolutions were measured by a pressure sensor (produced by Dytran Company, America) installed in the vessel wall and recorded by a data acquisition system for each run. These data yielded values of the maximum explosion pressure (P_m) and maximum rate of pressure rise $(dP/dt)_m$.

2.2. Experimental materials' characteristics

In the gases explosion experiments, high purity (99.99%) bottled methane (CH_4) and hydrogen (H_2) was used for the simulated hybrid mixtures and each gas contents were controlled by regulating the gas partial pressures. During the gas and coal dust hybrid mixtures experiments, three coal samples in different rank (such as anthracite, bituminous coal and lignite) were selected for the explosion investigations. The raw coal were crushed and screened according to particle size distributions of the coal mine dust. The ultimate and proximate analyses of the samples are summarized in Table 1. The size of coal dust particles were determined using a laser diffraction analyzer and particle sizes were characterized by dp_{10}, dp_{50} and dp_{90}, which are listed separately in Fig. 2. Before experiments, the coal dust samples were systemically dried about 2 h at 50 °C under vacuum condition for the removal of adsorbed moisture.

3. Results and discussions

3.1. Hydrogen yield from coal spontaneous heated process under the coal mine

Coal is a substance with significant complex chemical structures. Many research results presented that molecular hydrogen may be released in the gob zones or sealed fire zones underground coal mine [20–22].

In order to investigated the hydrogen yield rules, three coal samples were studied using coal spontaneous combustion analyzer under temperature-programmed conditions. A GC analyzer was employed for the hydrogen detection. Results (Fig. 3) show that hydrogen yield increases exponentially with temperature in the experimental ranges. For

Table 1
Ultimate and proximate analysis of coal samples.

Samples	Ultimate analysis (*w*/*w* %)					Proximate analysis (*w*/*w* %)				Calorific value (MJ/kg)
	C_{ad}	H_{ad}	O_{ad}	N_{ad}	S_{ad}	FC_{ad}	V_{daf}	A_{ad}	M_{ad}	
Anthracite coal	55.65	1.31	0.23	0.52	2.74	54.43	9.96	38.23	1.32	24.64
Bituminous coal	61.46	3.57	3.04	0.70	4.26	49.68	31.95	25.52	1.46	23.95
Lignite coal	33.57	2.51	10.03	0.23	2.15	25.62	47.16	46.27	5.25	17.39